STORAGE RELIABILITY OF MISSILE MATERIEL PROGRAM

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RAYTHEON

RAYTHEON COMPANY
EQUIPMENT DIVISION

LIFE CYCLE ANALYSIS DEPARTMENT
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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) STORAGE RELIABILITY OF MISSILE MATERIEL PROGRAM, IGNITERS AND SAFE & ARM DEVICE ANALYSIS.		5. TYPE OF REPORT & PERIOD COVERED FINAL June 1974 – June 1976
		6. PERFORMING ORG. REPORT NUMBER LC-76-OR2
7. AUTHOR(s) DENNIS F. MALIK		8. CONTRACT OR GRANT NUMBER(s) DAAH01-74-C-0853
9. PERFORMING ORGANIZATION NAME AND ADDRESS RAYTHEON COMPANY, EQUIPMENT DIVISION 3322 S. MEMORIAL PARKWAY HUNTSVILLE, ALABAMA 35801		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS HEADQUARTERS, U. S. ARMY MISSILE COMMAND Attention: DRSMI-QSD REDSTONE ARSENAL, ALABAMA 35809		12. REPORT DATE May 1976
		13. NUMBER OF PAGES 44
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

RELIABILITY, STORAGE, MISSILE MATERIEL, FAILURE RATES, FAILURE MECHANISMS, OPERATION, IGNITERS, SOLID PROPELLANT, ROCKET MOTORS, GAS GENERATORS, SAFE & ARM DEVICES, INERTIAL, MOTOR DRIVEN

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report summarizes analyses on the non-operating reliability of missile igniters and safe & arm devices. From the data analyzed aging is indicated for these devices after long term storage. The aging mechanisms and trends are given together with a reliability prediction model. This information is part of a research program being conducted by the U. S. Army Missile Command, Redstone Arsenal, Alabama. The objective of this program is the development of non-operating (storage) reliability prediction and assurance

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. Abstract (continued)

techniques for missile materiel.

STORAGE RELIABILITY
OF
MISSILE MATERIEL PROGRAM

IGNITERS AND SAFE & ARM DEVICE ANALYSIS

LC-76-OR2 MAY 1976

Prepared by: Dennis F. Malik
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FOR
HEADQUARTERS
U. S. ARMY MISSILE COMMAND
REDSTONE ARSENAL, ALABAMA

IN COMPLIANCE WITH
CONTRACT NO. DAAH01-74-C-0853
DATED 4 JUNE 1974
DATA ITEM SEQUENCE NO. 3

RAYTHEON COMPANY
EQUIPMENT DIVISION

LIFE CYCLE ANALYSIS DEPARTMENT
HUNTSVILLE, ALABAMA

ABSTRACT

This report documents findings on the non-operating reliability for Igniters used in Solid Propellant Rocket Motors and Gas Generators and for Safe and Arm Devices. Long term non-operating data has been analyzed together with accelerated storage life test data. A reliability prediction has been developed for various classes of Igniter and Safe and Arm Devices.

This report is a result of a program whose objective is the development of non-operating (storage) reliability prediction and assurance techniques for missile materiel. The analysis results will be used by U. S. Army personnel and contractors in evaluating current missile programs and in the design of future missile systems.

The storage reliability research program consists of a country wide data survey and collection effort, accelerated testing, special test programs and development of a non-operating reliability data bank at the U. S. Army Missile Command, Redstone Arsenal, Alabama. The Army plans a continuing effort to maintain the data bank and analysis reports.

This report is one of several issued on ordnance devices and other missile materiel. For more information, contact:

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SECTION 1

INTRODUCTION

Materiel in the Army inventory must be designed, manufactured and packaged to withstand long periods of storage and "launch ready" non-activated or dormant time. In addition to the stress of temperature soaks and aging, they must often endure the abuse of frequent transportation and handling and the climatic extremes of the forward area battle field environment. These requirements generate the need for special design, manufacturing and packaging product assurance data and procedures. The U. S. Army Missile Command has initiated a research program to provide the needed data and procedures.

This report covers findings from the research program on Solid Propellant Motor/Gas Generator Igniters and Safe and Arm Devices. The program approach on these devices has included literature and user surveys, data bank analyses, data collection from various military systems and special testing programs.

A reliability prediction has been derived from the storage time data and failure mode and mechanism knowledge.

SECTION 2

SUMMARY

Data from fourteen missile programs were analyzed. Out of approximately 45 million unit storage hours of solid propellant motor igniters, four igniter failures were reported. No failures were reported in 17 million unit storage hours of gas generator igniters. Definite aging trends were noted in the igniters.

Safe and arm devices were also analyzed with the igniters. Forty-Five failures were reported in 75 million unit storage hours for the safe and arm devices. Possible aging trends for these devices were also noted.

Reliability prediction models for the igniter and safe and arm device were developed which describe both the random type failure occurrence and the aging type failure characteristic.

Table 2-1 provides a summary of the reliability of these devices for 5 and 10 year periods. The prediction models used for these calculations are described in Section 5.

For programs which periodically test devices and replace them when specification failures exist, the replacement rate will be higher than that noted in the reliability calculations. Section 5 also gives statistics to calculate the specification reliability.

The data indicates that pyrogen igniters show less deterioration with age than pyrotechnic ingiters.

Motor driven safe and arm devices showed more deterioration with age than the inertial or manual device.

Table 2-1. IGNITER AND SAFE AND ARM DEVICE RELIABILITY

Device	Reliability (50% Confidence Level)		Reliability (90% Confidence Level)	
	5 Yr.	10 Yr.	5 Yr.	10 Yr.
Pyrogen Igniter	.9952	.9804	.9884	.9433
Pyrotechnic Igniter	.9922	.9854	.9785	.9581
Gas Generator Igniter	.9942	.9734	.9854	.9235
Inertial S&A Device	.9862	.9646	.9662	.9064
Manual S&A Device	.9941	.9883	.9910	.9820
Motor Driven S&A Device	.9584	.9429	.9394	.8956

SECTION 3
IGNITERS AND SAFE AND ARM DEVICE DESCRIPTION AND FAILURE MECHANISM DISCUSSION

3.1 Igniter Description

Igniters are rapid burning devices which develop a sudden evolution of heat and gas and in some cases hot particles. The gas produces a sharp pressure peak which may be of greater magnitude than the operating pressure of the rocket motor or gas generator.

The igniters are initiated by means of an electric squib. At least two squibs are used per igniter for reliability. Basically, the squib consists of a body in which are imbedded two electric leads, a bridge wire which shorts the leads and is heated by the passage of an electric current, and a heat-sensitive materiel normally applied as a bead to the bridge wire. A small booster charge of black powder or other pyrotechnic mixture may be part of the squib for initiation of the igniter. This charge and burnout wire are encased in a metal cup crimped tightly to prevent contamination. The squibs are designed not to fire until a certain critical electrical energy is applied. This allows continuity testing without danger of premature ignition. It also prevents the squib from firing from stray induced currents from electronic gear or power lines in the area.

Two basic types of igniters are used in current missile systems: pyrotechnic and pyrogen igniters.

3.1.1 Pyrotechnic Igniters

Pyrotechnic mixtures range from black powder with powdered metals to metal oxidants. A black powder/magnesium mixture is used in several igniters for which data has been collected. Metal oxidants have become replacements for black powder in some of the newer ignition systems. The most common mixtures contain magnesium, aluminum or boron powder and potassium nitrate or perchlorate. Granular mixtures usually react too rapidly, so the mixtures are

generally pressed into pellets.

The igniter container has been made of tin or plastic. For large rockets, a perforated tube may be used to contain the pyrotechnic. It may be half or more of the length of motor grain. In other designs, a plastic or metal can is used. The cover of the can ruptures at the initiation and the hot gases are released to the propellant grain.

3.1.2 Pyrogen Igniters

The pyrogen igniter is a small rocket motor used to ignite the main motor. The design used for pyrogens is, in general, similar to the main charge. The exhaust from the pyrogen is directed via a nozzle into the center perforation of the main motor; usually from the forward end. Fast burning propellants are used at moderately high pressures to obtain a high mass discharge rate. For very large motors the use of a pyrogen provides a better method of ignition.

The pyrogen is initiated by squibs and a pyrotechnic primer. Igniter charges generally consist of double base propellant materiels such as nitrocellulose and nitroglycerin.

3.1.3 Igniter Failure Mechanisms

The igniter generally experiences two categories of failure mechanisms. The first category is failures associated with the initiator, including failure of the lead wires and bridge wires in the squib. These failures usually lead to non-ignition. The failures may be a result of quality defects, handling damage, contamination or corrosion.

The second category is an aging characteristic in which pyrotechnic and/or propellant mixtures deteriorate with age. This deterioration generally results in a decrease in igniter pressure and long ignition delays. The deterioration may progress to a point of non-ignition.

The degradation of the ordnance materials with age may result from several causes. Package leaks caused by inadequate seals or cracked cases can allow moisture to deteriorate the materiels.

In addition, pyrogen propellants are subject to long term decomposition. This decomposition is slowed by the addition of stabilizers in the propellant mix.

3.2 Safe and Arm Devices

The safe and arm (S&A) device electrically isolates the igniter to prevent premature ignition of the propellant motor or gas generator and to allow for electrical testing of the ignition circuitry. In some cases, the S&A device also mechanically isolates the initiator (squibs and primer mixture) from the pyrotechnic mixture or pyrogen motor.

Data has been collected on three types of S&A devices: inertial rotary type; manual rotary type; and motor driven rotary type.

The inertial S&A device is used in the upper stage of a multistage missile. Acceleration of the booster stage provides the energy to activate the inertial device.

The manual rotary S&A device is activated for small missiles before or after it is loaded into the launcher.

The motor driven rotary S&A device is used for remote actuation.

The S&A device exhibit failure mechanisms such as those for switches in other applications. These include deformed, broken or loose contacts and contact springs, defective welds and/or solder joints, contamination, contact corrosion, and defective or damaged lead wires.

Possible aging mechanisms have also been noted which degrade arming times. This degradation is caused by corrosion of sliding surfaces and degradation of seals and packing.

3.3 Inspection and Quality Control

3.3.1 Igniters

Materiel inspection in process controls, radiographic and lot acceptance tests are utilized in varying degrees to assure the reliability of igniters. Data from statistical samples of each lot for acceptance tests can be utilized as a baseline for surveillance programs.

3.3.2 Safe and Arm Devices

Materiel inspection and quality conformance testing is used to assure reliability of the safe and arm device. The quality conformance tests include visual and mechanical examination and tests for torque, dielectric withstanding voltage, and contact resistance specifications. Environmental tests on lot samples are also utilized. These include thermal shock, vibration, shock, moisture resistance, salt spray as well as various other tests to insure the integrity of the device.

3.4 Surveillance Programs

Various surveillance programs have been established for different missile programs in the field to study the aging mechanisms and characteristics of ordnance devices and determine the effect of age on ballistic and structural performance. Samples for the surveillance tests may be selected at random from the missiles stored in the field or devices from specific lots may be specified and reserved solely for surveillance testing.

The surveillance program typically consists of periodic withdrawal of samples from storage, exterior inspections; radiographic inspections; internal inspections; chemical and physical properties testing; and ballistic results from static fired samples. The results are compared with acceptance test results and other previous surveillance tests. Trends in ballistic results are statistically analyzed to determine when the device may be deteriorated beyond acceptable performance. In some cases, rework programs have been initiated following surveillance tests to correct particular deteriorations and extend the useful life of the device.

3.5 Accelerated Test Programs

Several accelerated test programs have been conducted to attempt to anticipate the expected behavior in the field storage environment. Typically units are stored at a constant high temperature.

The Naval Ordnance Station at Indian Head uses a "type-life" program in which a number of units are stored under a "compressed-ambient temperature cycle" in controlled temperature

facilities. These units are subjected to periodic 6-month withdrawal from storage for environmental, static-firing, and detailed laboratory tests. The "compressed ambient temperature cycle" is designed to simulate the four seasons of the year by exposure of the test sample to various selected temperatures for definite periods of time. The standard cycle consists of 3 weeks at 70°F (Spring); 16 weeks at 100°F (Summer), 3 weeks at 70°F (Fall); and 4 weeks at 40°F (Winter).

The cycle allows the mechanisms of age to proceed without interruption during its 26-week, 6-month duration at a rate roughly equivalent to 1 year of magazine storage. In this manner, the maximum effects of both the reversible and irreversible chemical and physical properties and changes may be observed.

SECTION 4
DATA ANALYSIS

Data from surveillance of fourteen missile programs has been collected and analyzed.

Approximately 45 million unit storage hours of solid propellant motor igniters indicated 4 failures which would have failed to ignite the motor in 452 static firings and 952 missile firings. Of this data, 15 million unit storage hours with 295 static firings contained ballistic parametric data. Five specification failures were indicated, 3 of which would not have failed the mission requirements.

Approximately 17 million unit storage hours of gas generator igniters indicated no failures which would have failed to ignite the gas generator in 332 static firings. Of this data, 14 million unit storage hours with 274 static firings contained ballistic parametric data. Six specification failures were reported, none of which would have failed the mission requirements.

Approximately 75 million unit storage hours of safe and arm devices indicated 45 failures which would have failed the motor ignition requirements in 2212 unit tests. Ten units failed to arm and 35 units armed in insufficient time to meet mission requirements. Of this data, 65 million unit storage hours with 2016 unit tests, recorded arming times and circuit resistances. One hundred forty seven specification failures were indicated. These failures occurred on motor driven rotary safe and arm switches. Thirty five of these specification failures would have failed the mission requirements.

4.1 Data Classification

4.1.1 Igniters

Table 4-1 summarizes the data on solid propellant motor igniters and gas generator igniters. Four programs (A1, B, H and I) utilized pyrogen igniters for motor ignition. Six programs (A2, C, D, E, F and G) used pyrotechnic devices. The igniters in programs J, K, L and M represent gas generator igniters.

TABLE 4-1. IGNITER STORAGE DATA

Program	Application/ Igniter Type	No. of Units	Storage Hrs.	Accep. Spec. Failures	Simulated Mission Failures	Age of Units (Months)
A1	Solid Rocket Motor Igniter/Pyrogen	21	992,070	0	0	55
A2	Solid Rocket Motor Igniter/Pyrotechnic	74	5,007,070	2	2	93
B	Solid Rocket Motor Igniter/Pyrogen	34	1,542,490	0	0	62
C	Solid Rocket Motor Igniter/Pyrotechnic	65	2,490,030	-	0	52
D	Solid Rocket Motor Igniter/Pyrotechnic	13 23	314,630 769,420	0 -	0 0	33 46
E	Solid Rocket Motor Igniter/Pyrotechnic	38	1,040,980	-	0	38
F	Solid Rocket Motor Igniter/Pyrotechnic	51 31	2,198,760 1,527,160	1 -	0 2	59 67
G	Solid Rocket Motor Igniter/Pyrotechnic	102	5,007,070	2	0	67
H	Solid Rocket Motor Igniter/Pyrogen	74	473,770	-	0	9
I	Solid Rocket Motor Igniter/Pyrogen	878	23,526,075	-	0	37
J	Gas Generator Igniter	18	635,100	-	0	48
K	Gas Generator Igniter	86 40	4,075,590 2,346,220	0 -	0 0	65 80
L	Gas Generator Igniter	59	2,949,200	0	0	68
M	Gas Generator Igniter	129	6,640,810	6	0	71

These statistics are further summarized in Table 4-2 by three classifications: pyrogen solid rocket motor igniters; pyrotechnic solid rocket motor igniter; and gas generator igniters. Note in Table 4-2 that each classification contains two lines of data. The first line represents total unit storage hours and failures which would have failed mission requirements. The second line is a subset of this data which represents ballistic parameter tests with failures to meet original acceptance specifications.

The numerical data indicates the pyrogen igniter to be more reliable in storage than the pyrotechnic igniter. However, this data could be misleading. The four failures reported for pyrotechnic igniters were quality and handling related defects and included three broken wires and an electrical short caused by incomplete potting of a radiation interference filter assembly. Any of these failures could have occurred in the pyrogen igniters as well.

Long term storage does appear to affect pyrotechnic igniters more than pyrogen igniters. However, due to insufficient samples of failures, no conclusion can be reached at this time.

The gas generator igniters are essentially identical devices to the pyrotechnic motor devices except for size and pressure requirements. The data shows no gas generator igniter failures which would have failed the mission requirements. Six failures to meet original acceptance specifications were identified.

4.1.2 Safe and Arm Devices

Table 4-3 summarizes the storage data on safe and arm devices. Programs A1 and A2 utilize inertial switches; Programs C and D manual switches; and Program N motor driven rotary switches.

The motor driven rotary switch shows a relatively high failure rate as compared with the other switches. These switches were the only ones tested in a separate test program from the igniter. Arming and safing times were monitored.

TABLE 4-2. IGNITER STORAGE DATA BY MAJOR CLASSIFICATION

Classification	No. Units	Storage Hrs.	Spec. Failures	Simulated Mission Failures	Avg. Unit Age
Solid Rocket Motor Igniter					
Pyrogen	1007 (55)	26,534,405 (2,534,[illegible]0)	NA (0)	0 (NA)	36 (63)
Pyrotechnic	397 (240)	18,355,120 (12,527,770)	NA (5)	4 (NA)	63 (72)
Gas Generator Igniter	332 (274)	16,646,920 (13,665,600)	NA (6)	0 (NA)	69 (68)
TOTALS	1736	61,536,445	-	4	-

TABLE 4-3. SAFE AND ARM DEVICE STORAGE DATA

Program	Type	No. Units	Storage Hrs.	Accep. Spec. Failures	Simulated Mission Failures	Avg. Unit Age
A1	Inertial	21	992,070	0	0	65
A2	Inertial	74	5,007,070	10	1 (C)	93
C	Manual Rotary	65	2,490,030	-	0	52
D	Manual	13	314,630	-	0	33
	Rotary	23	769,420	-	0	46
N	Motor Driven	2016	65,104,320	147	9(C) 34 (S)	44
TOTALS						
	Inertial	95	5,999,140	10	1 (C)	87
	Manual Rotary	101	3,574,080	-	0	48
	Motor Driven	2016	65,104,320	147	9(C) 35 (S)	44

C = Catastrophic Failures

S = Specification Failures

Nine of the failures were indicated as catastrophic. The 35 specification mission failures were failures to arm in the necessary time to meet mission requirements. One hundred twelve additional specification failures were identified which would have fulfilled mission requirements. These switches showed definite aging trends in arming and safing times.

4.2 Aging Trends

4.2.1 Successes vs. Age

Figure 4-1 depicts the number of static or missile firings by age for the igniters. Also shown are the number of specification or mission failures as applicable. The success percentage for each year has been plotted to attempt to determine an aging trend. No trends are apparent in the data.

Figure 4-2 presents the same type of data for Safe and Arm (S&A) devices. A definite aging trend is indicated for the motor driven device. The percent of successful tests show a marked decrease with the age of the unit. A possible aging trend is also indicated for the inertial S&A device. The manual rotary devices are not shown since no mission or specification failures were reported.

4.2.2 Performance Parameters vs. Age

Five of the missile programs were able to project aging trends for individual ballistic parameters using the static firings at acceptance testing as a baseline. Figure 4-3 depicts the average percent change with time for the major classifications of igniters.

The pyrogen igniters showed the least change with age for burn time, maximum pressure and average pressure. The burn time increased while the maximum and average pressures decreased. These trends are identical to those described for double base solid propellant motors in Report LC-76-OR1. The trends are attributed to the inherently unstable propellant decomposing with age.

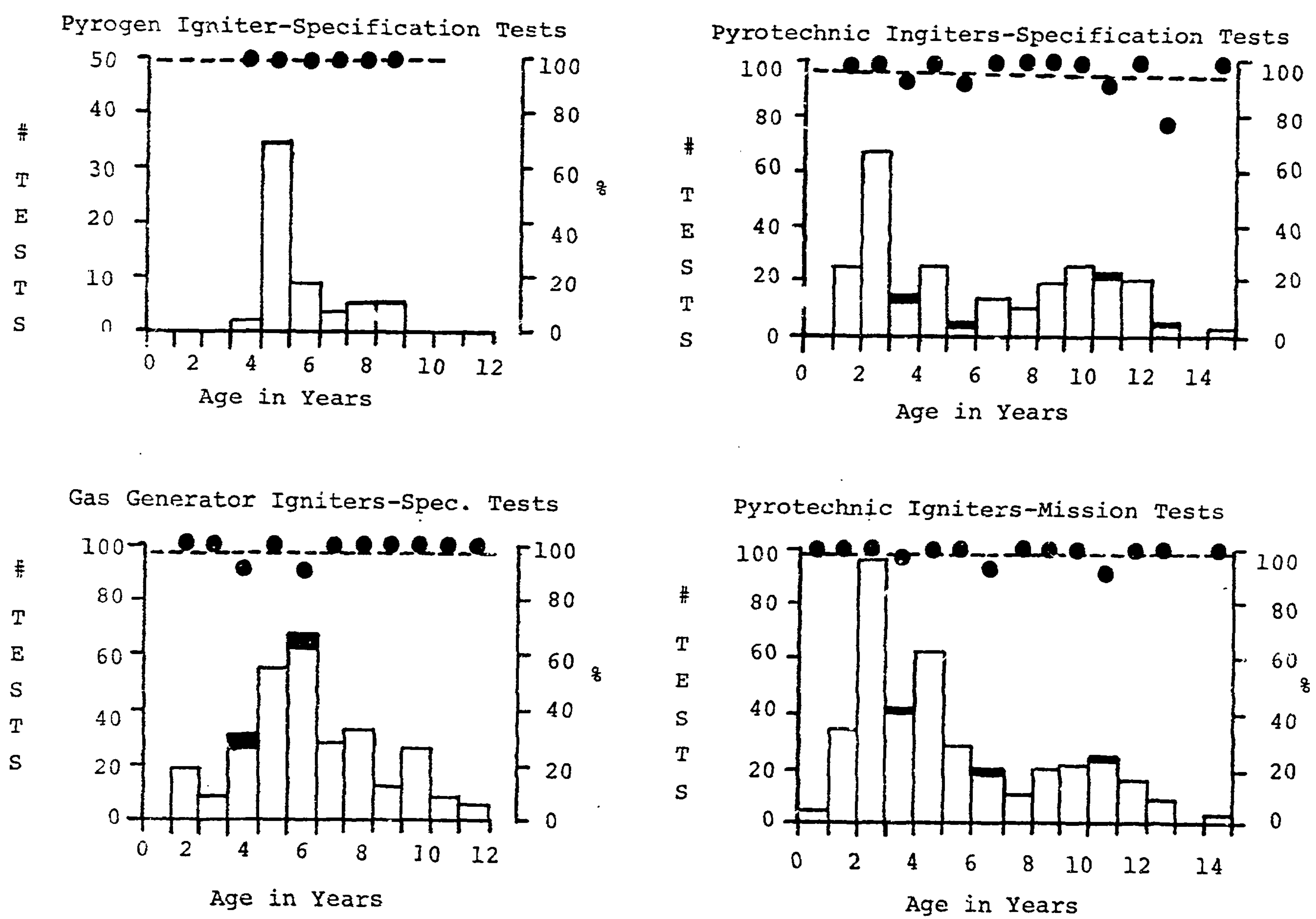
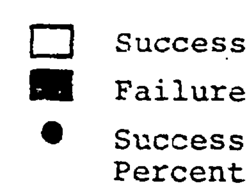


FIGURE 4-1. TREND OF IGNITER TESTS WITH AGE



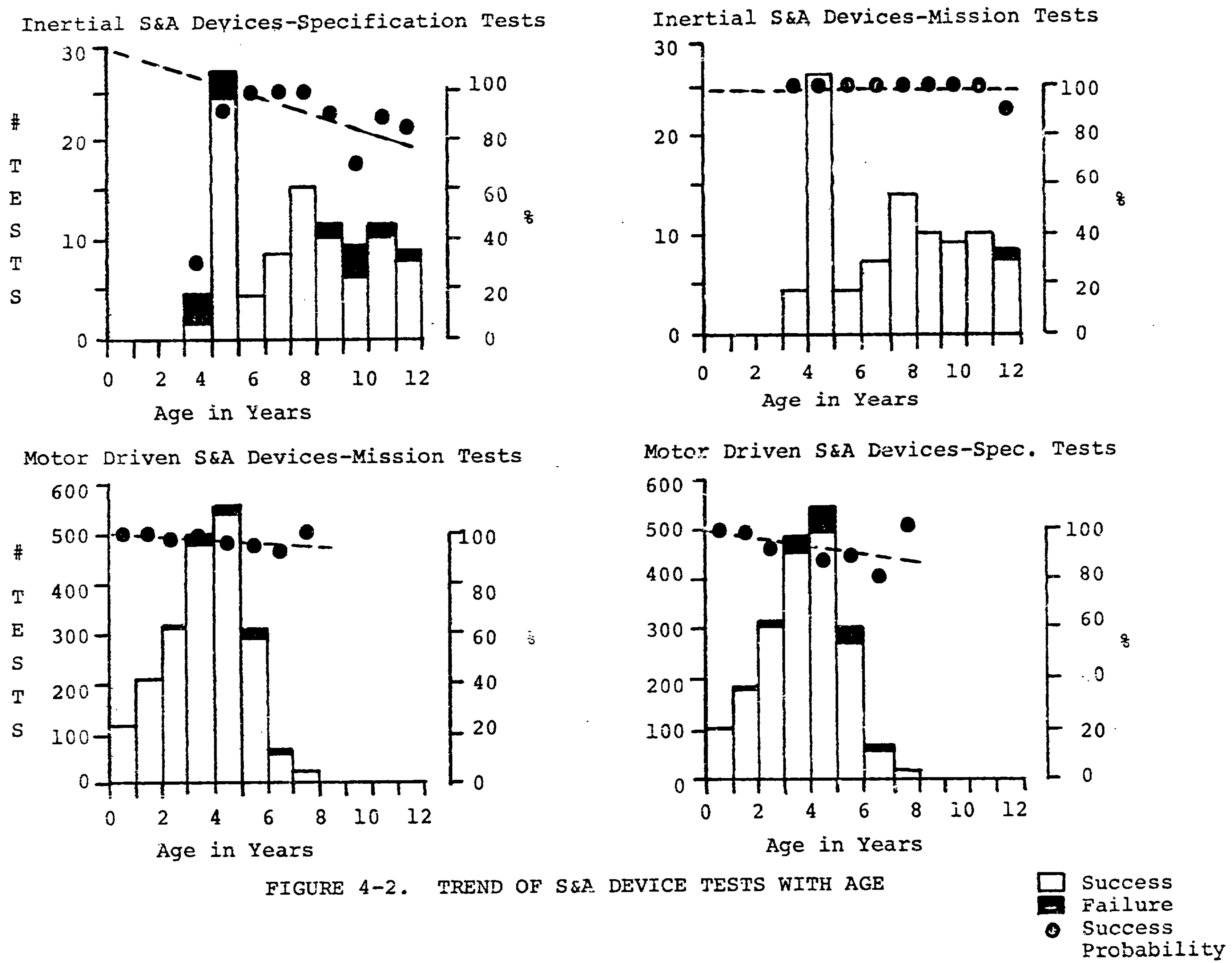


FIGURE 4-2. TREND OF S&A DEVICE TESTS WITH AGE

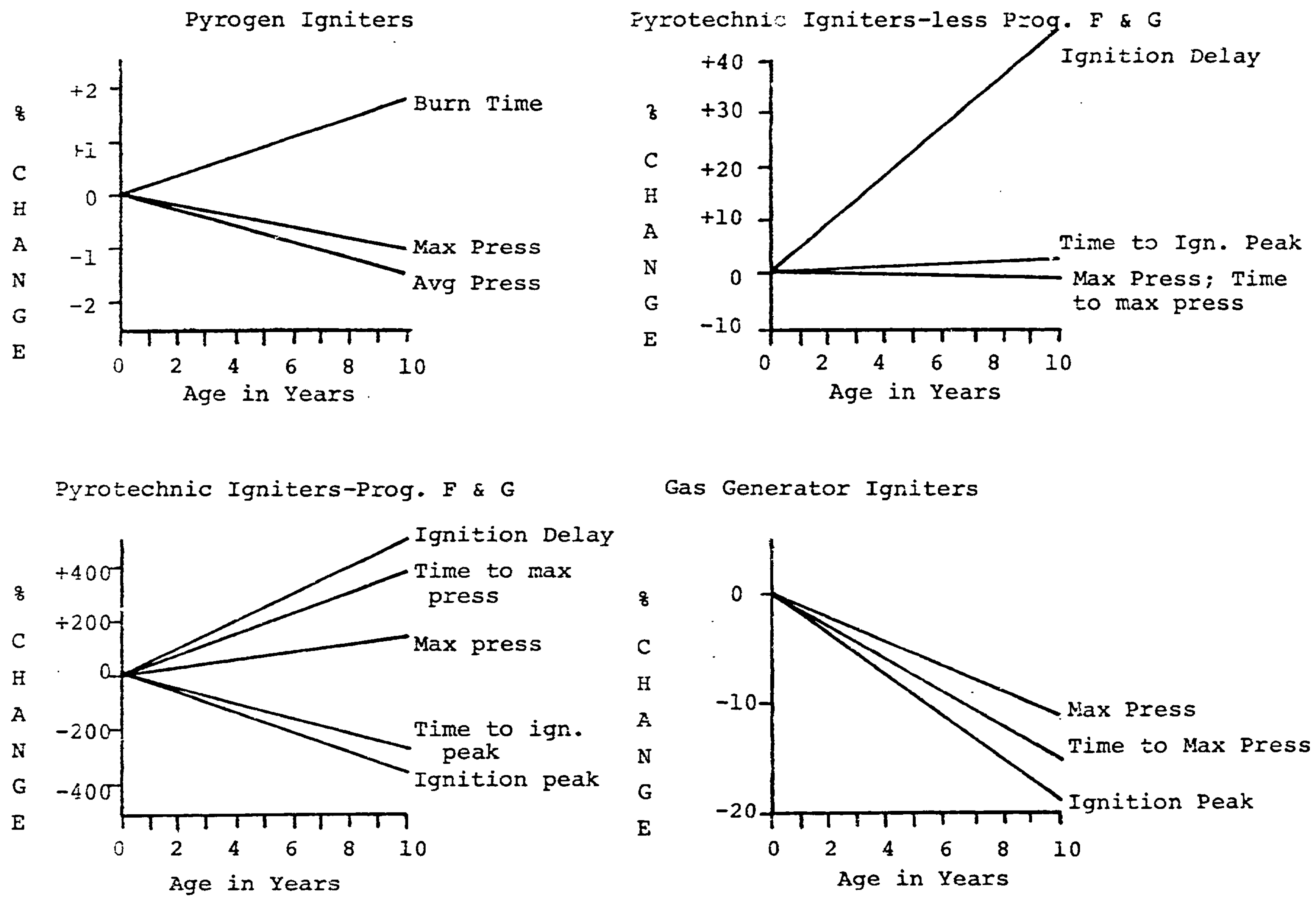


FIGURE 4-3. IGNITER PERFORMANCE AGING TRENDS

The pyrotechnic igniters showed larger changes with age than the pyrogen motor igniters. Data from Programs F and G were separated from Programs A2, C and D due to the much larger changes. Program F utilized accelerated testing and the extrapolation to real time may be inaccurate. All of the programs show an increase in ignition delay with age. This increase is due to two factors: the change in igniter ballistic characteristics and a change in the solid rocket motor ballistic characteristics. Maximum pressure and time to maximum pressure decreased for the pyrotechnic igniters except for Programs F and G which showed an increase in these parameters.

The gas generator igniters showed a decrease in the three parameters measured: maximum pressure, time to maximum pressure and ignition delay.

For the motor driven rotary safe and arm device, a large trend in increasing arming time was seen (approximately 13% increase per year).

4.3 Failure Modes and Mechanisms

Table 4-4 summarizes the failure modes experienced during the igniter static firing tests. Catastrophic failures are defined as failure to functionally perform and specification failures are defined as failures to be within original acceptance specifications.

The catastrophic failures were caused by quality and handling problems and were not related to age of the units. The nine specification failures were generally related to aging effects.

Table 4-5 summarizes the failure modes exhibited by safe and arm devices during tests. The failure of the inertial device was caused by a manufacturing defect. Specific failure causes were not given for the motor driven devices. See Section 4.5 for general failure modes of these devices.

Table 4-4. Igniter Failure Modes

Catastrophic Failures

Pyrotechnic Igniters

2 units - broken wire in harness
1 unit - broken squib bridge wire
1 unit - igniter electrical circuit shorted by RIF screen

Specification Failures

Pyrotechnic Igniters

1 unit exceeded maximum peak pressure specification
2 units failed minimum ignition delay specification

Gas Generator Igniter

6 units failed lower circuit resistance specification

Table 4-5. Safe and Arm Device Failure Modes

Catastrophic Failures

Inertial S&A Device

1 unit - blocked switch movement due to improperly manufactured cover

Motor Driven S&A Devices

57 units exceeded mission arming time requirements

Specification Failures

Inertial S&A Devices

6 units exceeded maximum arming time specification
4 units failed minimum arming time specification

Motor Driven S&A Devices

147 units failed maximum arming time specification

4.4 Other Defects Identified

Table 4-6 lists other defects noted in the devices, however none of these were detrimental to the device tests. As can be noted these defects range from quality problems to handling problems to possible aging problems.

4.5 Program Data

Detailed data on each of the missile programs for which surveillance data was available is included in the following sections.

4.5.1 Program A

The igniters in program A are used in the sustainer stage of the two stage missile. The igniter is electrically and mechanically armed by the acceleration of the missile during the boost phase of missile flight. Missile acceleration causes a g-weight to move which causes a rotary switch and a blocking rotor to rotate. Rotation of the blocking rotor arms the igniter mechanically by opening the ignition ports between the electrical squibs and the ignition pellets. The igniter is electrically armed by the rotation of the rotary switch, closing the igniter electric circuit.

Two different igniters have been used in the missile program designated here as igniters A1 and A2.

Igniter A1 consists of an Arming-Firing Device, a pyrogen motor, and a rocket motor nozzle assembly. The Arming-Firing Device consists of an inertial g-weight and an electrical switch, which mechanically and electrically arm the igniter, and two ignition squibs. The pyrogen motor contains a two-step ignition system consisting of a primary charge of $BKNO_3$ ignition pellets and a secondary charge consisting of a small arcite grain.

In igniter A1, the firing current is applied to the squibs which ignite the pyrogen motor. Hot gases from the pyrogen motor exhaust up the blast tube to the rocket motor propellant grain, causing the propellant grain to ignite.

Table 4-6. Other Unit Defects

Igniters

- 6 units frayed wiring harness
- 28 units cracked cover plate
- 2 units rust present
- 3 units wiring harness damaged
- 2 units improperly installed igniter connecting cables
- Twisted grains
- Hot gas seal defective
- Potassium nitrate depletion in igniter

Safe and Arm Devices

- Screws loose on gear train of inertial device
- Cover plate improperly placed
- Improperly placed safe and arm decal on manual switch

Igniter A2 consists of an Arming-Firing Device and a charge can. The Arming-Firing Device is similar to that of igniter A1. The charge can contains an ignition charge of Boron Potassium Nitrate ($BKNO_3$) pellets.

In igniter A2, the firing current is applied to the squibs which ignite the $BKNO_3$ pellets in the charge can. Ignition of the $BKNO_3$ pellets ruptures the charge can cover and the hot gases exhaust through the sustainer causing the propellant grain to ignite.

4.5.1.1 Igniter A1 Surveillance

Twenty one igniters were involved in the surveillance ranging in age from 45 to 91 months with an average age of 65 months. Visual inspection revealed that six of the igniters had frayed wiring harnesses, however, the wiring harnesses were not damaged seriously enough to have an effect upon the igniters operation. The pyrogen motor grains were in good condition upon X-ray examination.

Centrifuge tests of the Arming-Firing Device showed all devices to be within specification for time-to-arm and all devices passed the 6 g axial no-arm test.

All of the igniters meet specifications in the ballistic tests. No strong, distinct aging trends were indicated. However, the burn time appears to increase with age while average pressure and maximum pressure are decreasing with age. Table 4-7 gives the trends identified.

TABLE 4-7. IGNITER A1 BALLISTIC TRENDS

Ballistic Parameter	Preconditioning Temperature-°F	Average % Change per Year
Burning Time	10	+0.21
	120	+0.15
Max Pressure	10	+0.12
	120	-0.31
Avg Pressure	10	-0.19
	120	-0.12

4.5.1.2 Igniter A2 Surveillance

Seventy four igniters were involved in the surveillance ranging in age from 40 to 138 months with an average age of 93 months.

Visual inspections indicated the following: cracking of the charge can cover; rust; electrical harness damage; an improperly manufactured cover plate; and a misaligned gear train. Charge can covers are being replaced with one made of styrene butadiene which is not susceptible to cracking.

Three igniters were inoperable. The first had a broken ground wire apparently caused by abusive handling of the electrical harness. The second had a frayed harness with one broken wire. The third had an improperly manufacture coverplate which caused the arming socket to be improperly placed and interference between the rotary switch and the electrical contracts prevented the switch shaft from rotating.

The two wiring harnesses were repaired and all igniters went through centrifugal tests. Eleven igniters failed the centrifuge specifications for arming time. One failure was the igniter with the improperly manufactured cover plate discussed above. The remaining ten failures were just slightly out of spec and would have armed the missile motor successfully. Six of the igniters failed to arm within the maximum specified time. Four of the igniters were armed sooner than the minimum specified time. Causes for two of the specification failures were identified: the first was a misaligned gear train caused by two screws on the g-weight shafts being loose; the second was caused by another improperly manufactured cover plate.

Chemical tests of the $BKNO_3$ pellets indicated that the percent of potassium nitrate was slightly below the minimum specification.

Static firing of the 74 igniters indicated all igniters to be within ballistic specifications. Table 4-8 gives aging trends identified in the static firings.

Table 4-8. Igniter A2 Ballistic Trends

Ballistic Parameter	Average % Change per Year
Ignition Delay	+0.11
Maximum Pressure	-0.04
Time to Maximum Pressure	+0.03

4.5.2 Program B

The igniter for program B is part of a ram jet combustion system and acts as a back-up in case of failure of the primary ignition spark plug. The hot gas igniter has a burn-time of 80 to 100 milliseconds. It consists of two main sections, the body and the gas pressure cartridge. The body section has a propellant consisting mainly of nitrocellulose and nitroglycerin. The gas pressure cartridge houses four squibs terminated internally with an initiator followed by Boron Potassium Nitrate ($BKNO_3$) in pressed and powdered form and then a manufacturer formulation.

Thirty igniters were involved in the surveillance ranging in age from 50 to 61 months with an average age of 58 months. Visual and x-ray inspections revealed no defects. Ten units were ballistic tested as received; ten were subjected to shock-vibration tests before firing; and ten were subjected to auto ignition tests. All units were within specification limits in the ballistic tests. No ballistic trends were calculated in this surveillance. No safe and arm device was evaluated in this program.

4.5.4 Programs C and D

The igniters in programs C and D are identical and use a pyrotechnic design. A manual activated switch is used to arm the igniter.

One hundred and one units have been involved in various surveillance tests ranging in age from 9 to 75 months with an average age of 48 months. Eighty eight igniters were tested as part of the solid propellant motor tests. Thirteen igniters were static fired independent of the motor and ballistic parameters measured.

For the igniters tested concurrent with the solid propellant motor, igniter circuit resistance and arming torque were measured and the units visually inspected.

Two motors failed to have the igniter connector in the proper position which may have interfered with the arming function. One motor had the safe and arm decal in the wrong position which could have resulted in a non ignition caused by personnel misjudgment of the full arming position. Arming torque on two motors exceeded the specifications. Changes in lubrication on newer igniters has corrected this problem.

All units ignited the motors satisfactorily. In the solid propellant motor tests ignition delay is the only ballistic parameter related to the igniter. The ignition delay parameter may be affected both by aging of the igniter and the motor itself. The trend in ignition delay for the eighty eight tests indicated an increasing ignition delay on the order of 0.36 percent per year.

Static firing of the thirteen igniters independent of the motors showed no failure either functionally or catastrophically. Table 4-9 gives aging trends identified in the static firings.

Table 4-9. Programs C and D Ballistic Trends

Ballistic Parameter	Average % Change per Year
Maximum Chamber Pressure	-0.03
Ignition Rise Time	+0.24

4.5.4 Program E

The igniter for program E utilizes pyrotechnic pellets. No detailed description of the igniter was available. Also, no safe and arm device was evaluated with the program.

Thirty eight igniters were involved in surveillance testing ranging in age from 11 to 75 months with an average age of 38 months. The igniters were tested as part of the solid propellant motor tests. No visual defects were detected and all igniter circuit resistances were within acceptable requirements. All motors were ignited satisfactorily. Trends in ignition delay time indicated an increase of approximately 0.78 percent per year for motors

conditioned at 20°F and a decrease of 4.0 percent per year for motors conditioned at 130°F.

4.5.5 Program F

The igniter for program F utilizes a black powder/magnesium mixture. The igniter includes a radiation interference filter. No safe and arm device was evaluated with the program.

Eighty two igniters were involved in surveillance testing ranging in age from 6 to 72 months with the average age being 32 months. All of the igniters were subjected to accelerated storage conditions which consisted of 3 weeks at 70°F, 4 weeks at 40°F, 3 weeks at 70°F and 16 weeks at 100°F. These conditions are estimated to approximately double the aging rate of the units.

Thirty one igniters were tested as part of the solid propellant motor tests. The remaining 51 igniters were subjects of individual static firings and ballistic measurements.

Two units failed electrical continuity tests. The first failure was a result of insufficient potting compound on the radiation interference filter which allowed the mesh screen on the back to make contact with the internal circuitry. The second failure resulted from a separation of the center-pin/bridge wire weld within the squib. It appeared to be caused by over torqueing of the nut on the igniter post.

With the exception of the two units described above, the remaining motors were ignited successfully.

X-ray examination of the other igniters indicated twisted grains both in prestorage inspection and surveillance inspection. It was determined that the twisted grains were caused during production and no further distortions resulted from age. All igniters were static fired successfully and were within the specification ranges. Table 4-10 gives aging trends identified in the static firings. These trends are extrapolated to normal storage environments.

Chemical tests of the igniter grain indicate a decreasing heat of explosion with age with the largest decrease occurring at six months and leveling off in remaining tests.

Table 4-10. Program E Ballistic Trends

Ballistic Parameter	Preconditioning Temperature-°F	Average % Change per Year
Delay Time	-65	+3.1
	70	+4.7
	165	+6.3
Ignition Peak	-65	-3.0
	70	-3.4
	165	-3.0
Time to Ignition Peak	-65	+0.1
	70	-3.2
	165	0
Peak Pressure	-65	+2.4
	70	+1.7
	165	+0.7
Time to Peak Pressure	-65	+3.6
	70	+4.0
	165	+3.4

4.5.6 Program G

The igniter for program G consists of a black powder/magnesium mixture and two squibs. No safe and arm device was evaluated in this program.

One hundred two igniters were tested as part of the solid propellant rocket motor tests. The igniters ranged in age from 19 months to 169 months with an average age of 67 months.

All motors were ignited successfully. Two motors failed the ignition delay specification: one exceeded the maximum ignition delay and one failed the minimum ignition delay. The trend in ignition delay was an increase with age on an average of 3.3 percent per year.

4.5.7 Programs H and I

The data for programs H and I consisted of actual missile flight tests. Igniter data consisted of mission success or failure identification. No failures were identified.

Program H included 74 test firings with igniters ranging in age from 1 to 51 months for an average age of 9 months.

Program I included 878 test firings with igniters ranging in age from 1 to 145 months for an average age of 37 months.

4.5.8 Program J

The igniter for program J is used in a gas generator which produces high pressure gas to power a control servo-mechanism and a turbo-electric alternator.

Eighteen igniters were tested as part of the gas generator tests. The igniters ranged in age from 36 months to 56 months with an average age of 48 months. All igniters performed satisfactorily in the tests.

The only parameter measured applicable to the igniters was ignition delay. The trend in ignition delay was an increase of approximately 0.3 percent per year.

4.5.9 Program K

The igniter for Program K is used in two gas generators which produce electrical and hydraulic power. The igniter contains zirconium and ammonium perchlorate which is electrically ignited.

Eighty six units were tested independent of the gas generators. Two units failed the maximum pressure specification. The failures were marginal and would have successfully ignited the gas generator. The igniters ranged in age from 12 months to 94 months with the average age being 65 months.

Forty additional units were tested as part of the gas generator tests. These igniters ranged in age from 37 months to 100 months with the average age being 80 months. All igniters performed satisfactorily in the tests.

Table 4-11 gives the ballistic parameter trends with age identified in the static firings.

Table 4-11. Program K Igniter Parameter Trends

Parameter	Preconditioning Temperature-°F	Average % Change per Year
Maximum Pressure	0°F	-1.8
	70°F	-1.9
Time to Maximum Pressure	0°F	-0.8
	70°F	+5.4
Ignition Delay (Igniter tests)	0°F	-3.2
	70°F	-2.4
Ignition Delay (Gas generator tests)	20°F	-1.9
	125°F	-3.2

4.5.10 Program L

The igniter for program L is used in a gas generator which produces gas to operate a turbo-electric generator.

Fifty nine units were tested as part of the gas generator tests. The units ranged in age from 55 months to 135 months with the average age being 68 months.

All igniters successfully ignited the gas generators. Ignition delay time trends were not apparent from the firings.

4.5.11 Program M

The igniter for program M is used in two gas generators which supply electrical power and hydraulic power. The igniter consists of a primer charge of lead styphnate, a booster charge of powdered boron potassium nitrate ($BKNO_3$) and a sustainer charge of pressed $BKNO_3$.

One hundred twenty nine units were tested as part of the gas generator tests. The igniters ranged in age from 22 months to 110 months with an average age of 71 months.

All units passed visual inspection and were successfully static fired. Six units failed the lower specification limit for circuit resistance.

Trend analysis indicated a decrease in maximum pressure averaging 0.9 percent per year and an increase in the time to maximum pressure averaging 0.4 percent per year.

4.5.12 Program N

The surveillance conducted in Program N involved motor driven safe and arm switches. Data on 2017 switches were analyzed ranging in age from 12 months to 96 months; averaging 44 months. Thirty specification failures were reported in which the circuit resistances were out of specification. Eighty four specification failures were reported in which arming or safing times exceeded original acceptance specifications. Of these, 35 failures were reported in which arming times exceeded minimum mission requirements. Acceptance specifications were set at a maximum of 1000 milliseconds arming and safing time, while mission requirements were a maximum of 2000 milliseconds. In addition, 9 failures were reported on failure to arm or disarm.

No detailed failure mechanism analysis was performed, however, age sensitive items were noted. These included swelling, cracking and general materiel degradation of O-rings, packing and insulators. Corrosion of bearings, contacts, switch ports, gear assemblies and motor armature were also postulated. Load relaxation of helical compression springs and bonding of friction plate clutch assembly were also noted.

Eighty percent of the failures involved long arming times. An age trend analysis was performed on the parametric data. The analysis indicated an average increase in arming time of 13 percent per year.

SECTION 5
RELIABILITY PREDICTION ANALYSIS

5.1 Mission Reliability

The data collected todate indicates two separate characteristics effecting the reliability of igniters and safe and arm devices. The first is a random failure event associated with quality and handling problems. The second is an aging characteristic. The reliability of the igniter or safe and arm device can therefore be defined as a function of the two characteristics:

$$R(t)_{\text{igniter or S\&A device}} = [R(t)_{\text{aging}}] \times [R(t)_{\text{random}}]$$

5.1.1 Igniters

Four random type failures were noted in approximately 62 million storage hours giving a failure rate of 65 failures per billion hours at the 50% confidence level and 129 failures per billion hours at the 90% confidence level.

No failures attributable to aging were reported. However, ballistic trends do indicate a definite deterioration with age. Aging reliabilities were therefore calculated based on binomial confidence levels for the number of successes in the fifth and tenth years. Figure 5-1 gives the igniter reliability prediction model based on these calculations.

The variation in reliabilities for age related failures is strictly a function of the number of data samples available for each igniter classification. The measured reliability for aging characteristics was 1.000 for all units.

Based on each program analysis, the recommended service lives for the propellant units were 8 to 10 years for pyrogen igniters; 9 to 14 years for pyrotechnic igniters; and 6 to 12 years for gas generator igniters.

5.1.2 Safe and Arm Devices

The catastrophic failure for the inertial safe and arm (S&A) device was attributed to a quality defect. The failure causes in the motor driven S&A devices were not analyzed but appeared to be a combination of quality defects and an aging trend. No aging deterioration of the manual rotary switches was evident in the data.

FIGURE 5-1. IGNITER RELIABILITY PREDICTION MODEL

$$R(t)_{igniter} = [R(t)_{aging}] \times [R(t)_{random}]$$

$$R(t)_{random} = \exp(-\lambda t)$$

	R(t) Aging				λ	
	50% confidence		90% confidence		50% Confidence	90% Confidence
Classification	5 yrs.	10 yrs.	5 yrs.	10 yrs.		
Solid Rocket Motor Pyrogen Igniters	.998	.986	.994	.954	65×10^{-9}	129×10^{-9}
Solid Rocket Motor Pyrotechnic Igniters	.995	.991	.984	.969	65×10^{-9}	129×10^{-9}
Gas Generator Igniters	.997	.979	.991	.934	65×10^{-9}	129×10^{-9}

Ten random type failures were noted in approximately 75 million storage hours giving a failure rate of 134 failures per billion hours at the 50% confidence level and 207 failures per billion hours at the 90% confidence level.

Aging type failures were reported for the motor driven switches and degradation of inertial switch arming time was also seen although no mission failures were reported. Aging reliabilities based on binomial confidence levels for the number of successes and failures during the fifth and tenth year were calculated. Figure 5-2 gives the S&A device reliability prediction model based on these calculations.

The variation in reliabilities for age related failures of inertial switches is strictly a function of the number of tests performed. The measured aging reliability was 1.000. For motor driven switches, however, 12 failures were experienced at the 5 year tests.

5.2 Specification Reliability

The same type of analysis was performed on specification reliability. Here, failure is defined as failure to meet acceptance specification even though some or all may have performed successfully the mission function.

Figures 5-3 and 5-4 give the specification reliability models for igniters and safe and arm devices respectively. While mission reliability predicts the probability, the missile performs its function, specification reliability predicts the probability of a unit requiring repair or replacement.

FIGURE 5-2. SAFE AND ARM DEVICE RELIABILITY PREDICTION MODEL

$$R(t)_{S\&A\ device} = [R(t)_{aging}] \times [R(t)_{random}]$$

$$R(t)_{random} = \exp(-\lambda t)$$

	R(t) aging				λ	
	50% confidence		90% confidence		50% confidence	90% confidence
Classification	5 yr.	10 yr.	5 yr.	10 yr.		
Inertial S&A	.992	.976	.975	.923	134×10^{-9}	207×10^{-9}
Manual S&A	1.000	1.000	1.000	1.000	134×10^{-9}	207×10^{-9}
Motor Driven S&A	.964	.954*	.948	.912*	134×10^{-9}	207×10^{-9}

*Extrapolated from 1 through 8 year data.

FIGURE 5-3. IGNITER SPECIFICATION RELIABILITY PREDICTION MODEL

$$R(t)_{igniter} = [R(t)_{aging}] \times [R(t)_{random}]$$

$$R(t)_{random} = \exp(-\lambda t)$$

Classification	R(t) aging				λ	
	50% Confidence		90% Confidence		50% confidence	90% confidence
	5 yr.	10 yr.	5 yr.	10 yr.		
Solid Rocket Motor Pyrogen Igniters	.987	*	.960	*	65×10^{-9}	129×10^{-9}
Solid Rocket Motor Pyrotechnic Igniters	.982	.975	.958	.942	65×10^{-9}	129×10^{-9}
Gas Generator Igniters	.964	.935	.950	.870	65×10^{-9}	129×10^{-9}

*No data at 10 years.

FIGURE 5-4. SAFE & ARM DEVICE SPECIFICATION RELIABILITY PREDICTION MODEL

$$R(t)_{S\&A\ device} = [R(t)_{aging}] \times [R(t)_{random}]$$

$$R(t)_{random} = \exp(-\lambda t)$$

	R(t) aging				λ	
	50% Confidence		90% Confidence		50% Confidence	90% Confidence
Classification	5 yrs.	10 yrs.	5 yrs.	10 yrs.		
Inertial S&A Device	.950	.840	.905	.730	134×10^{-9}	207×10^{-9}
Manual S&A Device	1.000	1.000	1.000	1.000	134×10^{-9}	207×10^{-9}
Motor Driven S&A Device	.890	.809*	.880	.800*	134×10^{-9}	207×10^{-9}

*Extrapolated from 1 through 8 year data.

SECTION 6

CONCLUSIONS AND RECOMMENDATIONS

The data analyzed for igniters and safe and arm devices indicated both random type and aging type failures. A considerable amount of data was analyzed on age related degradation. However, for a number of devices, the lack of a large failure sample tends to make the reliability predictions conservative. Until more data is available, it is recommended that the reliability prediction models in Tables 5-1 and 5-2 be used.

The data indicated that the pyrogen igniters show less deterioration with age than the pyrotechnic igniters. Therefore, pyrogen igniters should be considered for all applications.

Missile system design should compensate for age changes in igniters performanced as described in Section 4.2.2.

Surveillance programs to detect excessive aging of igniters are recommended.

The aging trends for safe and arm devices have not been identified in other switch applications. A possible reason is the tight specifications on the operating time of the safe and arm devices. In other switch applications with less stringent specifications, the aging trend may not be apparent.

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